Coordinated Sampling Strategy to Map and Characterize the Vertical and Horizontal Disposition of any Submerged Oil Plume(s) Arising from the Deep Water Horizon (DWH) Spill (v1)

The primary objectives of this sub-surface sampling strategy are to:

1. Establish where the subsurface oil is located within the water column and how is it changing over time; and
2. Understand the effects of the subsurface oil, especially in deep water. This would certainly be from an ecosystem perspective, but will need to consider species and communities at risk and effects of oil/dispersed oil.

Principal Sub-surface Sampling Plan Elements:

1. Definition of Requirements
2. Validation of Sampling Techniques
3. Identification and Deployment of Platforms and Sensors
4. Mapping, Modeling, and Analysis (including biological component)
5. Data Management and Logistics

For each of these elements the proposed approach and current status are provided. **Strategy elements will be updated based on transition from immediate response needs to longer term monitoring – this document is based on knowledge to-date.**

Definition of Requirements

Approach – Recognizing the three principal time horizons (primary: response; intermediate: damage assessment; and long-term: research/monitoring) this sub-surface sampling effort is being coordinated across the unified response. Prior to the identification or deployment of sampling assets the actual needs must be defined.

Current Status – Operational requirements have already been determined for the response efforts, based on input from the NOAA response teams, unified command, Responsible Party (BP), and contracted responders. These immediate needs include:

- Establishing presence or absence of oil through the water column;
- Quantifying concentration and composition of oil and particle size in the water column;
- Producing temperature profiles and salinity gradients through the water column;
- Mapping any oil plume boundaries through direct observations and measures; and
- Forecasting movement and changes of any oil plume(s).

The intermediate and longer-term sampling requirements include assessment of impacts to the biological community and society and will be addressed using a comprehensive ecosystem-based approach. These needs can be more clearly defined by the research community, including the NOAA Research Council.

Validation of Sampling Techniques and Initial Mapping

Approach – Before any major deployments occur the sampling strategy will be guided by an immediate validation effort designed to identify the optimal methods for detecting and characterizing any sub-surface oil. Optimally, this validation effort would take place from a research vessel with the ability to tow and deploy a range of in situ sensors, in combination with water sample collection and analysis. Once specific observing techniques have been validated (and others precluded), decision can be made about subsequent sensors and appropriate platforms for those payloads.

A recommended approach includes deploying a research vessel on site near the wellhead to conduct a series of validation measurements. It is likely that there are characteristic signatures of subsurface plumes in the acoustic backscatter profile (strong signal returns from the oil at frequencies < 30 kHz – see http://www.aoml.noaa.gov/ocd/ixtoc/Ixtoc_home.htm for information about use of this technology during the Ixtoc spill) and in the vertical temperature profile and that can be used as proxy measures of the plume. It is suspected this is a signature of the plume. The vessel needs to execute validation studies to understand how this and other proxies (e.g., presence of thermostad) could be used.

If such proxies are validated it will permit relatively inexpensive and widely available technologies to be used to more completely map out the plume. Platforms could include a number of gliders, AUVs, and probes. The plume, if it exists, may cover an extensive footprint and be complicated in shape (i.e., not a simple ellipse). Should these proxies be found to not be reliable an alternative mapping effort will need to be undertaken that uses more sophisticated techniques (optical or chemical) that will take longer to mobilize and which will likely progress more slowly. Coordination of the assets used in the mapping and analysis of the observations will be supported by regional oceanographic experts.

Once an initial mapping of the plume is accomplished circulation models can be used to forecast plume growth and movement. Neutral buoyancy floats could be used to seed the plume in select locations to provide regular tracking.

One potential analysis team is the Geochemical and Environmental Research Group (GERG) at Texas A&M who could conduct detailed hydrocarbon analyses and the NOAA/OAR/AOML in Miami may be available to conduct hydrocarbon fluorometry surveys. The R/V Seward Johnson might be available prior to a cruise in the South Atlantic (off Brazil). We propose that the Johnson (or similarly equipped vessel) will steam to an appropriate port for loading (Gulfport?) then conduct field studies for 4 days near the wellhead. Details include:

I. The necessary scientific / measurement systems for be carried by the vessel conducting the validation studies will include: (1) a CTD (ship borne), (2) expendable temperature probes , (3) an active acoustic backscatter system operating generally below 30 kHz, (4) Oil detecting (lowerable) and other types of fluorometers (5) a low-frequency ADCP to obtain full-depth current profiles, (6) a LISST system for particle size evaluation, and (7) water sampling devices (Rosettes or others) to sample depths likely to contain entrained oil (as indicated by acoustics and temperature probes). Sampling will also be conducted above and below the entrainment depths. It is important to note that the AXBTs which suggest a plume at 100 m depth were limited to sampling of the upper 350 m of the water, therefore there may be deeper plumes. An examination for plumes over the full range of water depths at the wellhead is crucial.

II. The ship sampling pattern will be a broad circle about the wellhead (roughly at 1-4 km radius from the wellhead at the surface but to be determined in consultation with incident command based on obstructions, vessel traffic and other potential conflicts). The submerged oil may have migrated in more than one direction. Concentric circles at increasing radii should be occupied until the shape of the plume becomes clear. After completion of the circle pattern, a series of plume transects (roughly normal to the suspected direction of motion of the plume) at increasing ranges should be conducted (more detail is provided below). Each plume transect should be mapped using a different asset (ship or aircraft) using standard search and rescue algorithms.

III. Cautions: lowered or towed equipment is likely to be fouled by any oil encountered. Appropriate cleaning equipment should be used to treat equipment after use and appropriate certifications/training for all those on the vessel are needed.

IV. Background Data: The ship will also seek to detect naturally occurring biological horizons (layers of plankton) in the water column in order to observe the depth (and other relationships) of the submerged oil and biological horizons (associated with plankton). While thermostads are unexpected in the upper water column they are more common at depth and associated with rings. Vessels already on site may yield valuable data from echosounder traces. Also, ADCPs on nearby rigs should be examined for any signatures of a plume.

V. Real time data: Real time acoustic backscatter data will be displayed aboard ship to support the sampling plan. Transects close to (or near) the wellhead could reveal the plume profile from the wellhead to the submerged oil horizons, thereby hopefully unambiguously relating wellhead to plume (this should be confirmed by independent sampling).

VI. Additional sampling: If possible appropriate gear for sampling plankton should be included on the initial missions, to help characterize biological conditions.

It is important to note that the ability to map the plume with simple techniques such as temperature profiles and acoustic backscatter enable the larger exercise to be conducted at limited expense. Should these techniques prove ineffective more sophisticated techniques like fluorometry will be required and will also be evaluated. The expense of the mapping exercise will increase dramatically because of the need to clean sensors after fouling (potentially after every cast) and the potential loss of expensive equipment (e.g., the loss of a $100,000+ glider due to buoyancy issues, fouling, or other causes). It is well worth the effort to establish the validity of simple techniques because of the cost benefit and avoided equipment loss more sophisticated approaches are expected to incur.

It will be critically important to coordinate the sampling with the existing command. Numerous obstructions exist in the vicinity of the wellhead, and use of acoustics must be approved. The studies cannot effectively proceed unless this acoustic transmission constraint is removed.

Current Status – There are already a number of sampling efforts underway in the Gulf of Mexico as part of the ongoing response to the DWH spill. These include remote sensing, shoreline assessments, ship-based sampling, and limited sub-surface sampling. To-date there has been limited coordination due to the scale and complexity of the response, and also due to the overwhelming offers of assistance. However, these data are available to the unified area command and incident command personnel via a NOAA-managed ftp site.

Some validation efforts are currently being carried out, based on sampling and analysis efforts supported by NOAA, BP, and several regional research institutions (e.g., LUMCON, TAMU). The results of these validation efforts are still being processed and relayed to the area command. Additional measurements (AXBTs, CTDs) are being made via the NOAA Gordon Gunter and NOAA/AOML P3-based flights. Ongoing ADCP-based measurements are available from oil and gas industry platforms in the Gulf.

An outstanding need is to document and implement a scientifically valid protocol for method and data validation/verification. The NOAA Research Council, in collaboration with the ocean science community can provide specific guidance on this aspect.

Identification and Deployment of Platforms and Sensors

Approach – Based on the results of the validation efforts, specific assets and deployments can be identified and established. The U.S. IOOS community, along with the operational response teams, have already established a working list of available observing assets including vessels, gliders, AUVs, and probes. These assets are being evaluated in the context of meeting the needs listed above, and how quickly they can be deployed. Decisions about deployments will be driven by the identified needs, and made by the unified command in consultation with the relevant science experts and operational leads.

Current Status – There are already several sampling and research cruises underway in the Gulf, and more recently (17 May 2010) the first of several sub-surface gliders have been deployed. The sensor payloads vary, but all data is being directed back to area command for use. These early deployments can help establish some of the operational challenges and also provide important baseline condition data for future analysis.

Mapping, Modeling, and Analysis

Approach – Once the sub-surface sampling is fully underway the resulting data will be passed to expert circulation and 3-D modeling teams at NOAA and regional research institutions with expert knowledge of the Gulf of Mexico. Direct observations will also be passed to the field teams for additional validation. Several 3-D models will be used, in combination with other circulation models. There is an immediate need to clarify the most appropriate models. Expertise resides within NOAA, University of South Florida, and NC State University.

Once one or more proxies to identify subsurface plumes are validated the mapping activity can begin in earnest. Based on considerable observational data collected near the spill site [e.g. Hallock et al., 2009] it is likely that the plume(s) have moved along isobaths to the east and west of the spill site. The currents are expected to be dominated by bottom-trapped topographic waves with periods of weeks and amplitudes of 10-30 cm/s. These currents are typically strongest near the bottom, and it is possible that deep plumes are of greater spatial extent than surface features. Given that several weeks have passed since the initial accident, it is also possible that any plumes have developed more complex shapes. Incursion of the Loop Current or associated eddies over the sites will complicate the flows and could induce cross-isobath circulation. Hence we anticipate an extensive mapping exercise that will take weeks to execute, possibly months. The plume may extend 100s of km from the wellhead in several directions. It is recommended that each arm, at each depth horizon, be mapped using a dedicated asset, either a ship or aircraft. If the arm is not mapped before the asset must return to port, a replacement vessel will need to re-acquire the plume and continue the mapping.

The preferred assets, if validated, are the use of XBT or AXBTs and low-frequency acoustics. Aircraft can use AXBTs very effectively. Standard vessels can utilize XBT and acoustics. Any assets operating in the area should collect visual records of surface oil distributions for use in validation. An expected sampling plan for vessels would be to use acoustics to identify the plume and XBTs to confirm the presence of a thermostad. The plume width is difficult to predict but is possibly of order 10 km and suggests XBT launches should be conducted every 3 km or so. Assuming 20 km cross-plume transects and 10 km along-plume spacing would require 60 XBTs to map 100 km plume, executed in a radiator pattern (e.g. Figure 1). Assuming this 100 km plume section is mapped from a vessel steaming at 10 knots it would take roughly 20 hours to complete. Some water sampling should be conducted to confirm the presence of oil and to examine its composition. Assuming a limited set are collected it is reasonable to expect 100 km plume could be mapped in one day. Slower ship speeds may be required to avoid cavitation and the associated loss of range/sensitivity of the acoustic profiling and would lengthen the sampling time.

If reliable proxies are not identified, then fluorometry and water samples will need to be used; this will greatly slow the mapping and necessitate extensive cleanup during sampling to keep the sensors optional. Platforms for use under this option include towed bodies, AUVs and gliders, though they will need to be matched to the depths of the plume(s), that is, the operating depths of the platforms will need to be capable of capturing the depth of the oil plumes. Fouling and clean-up are serious concerns because of a lack of experience with operation of these types of platforms in a heavily-oiled environment.

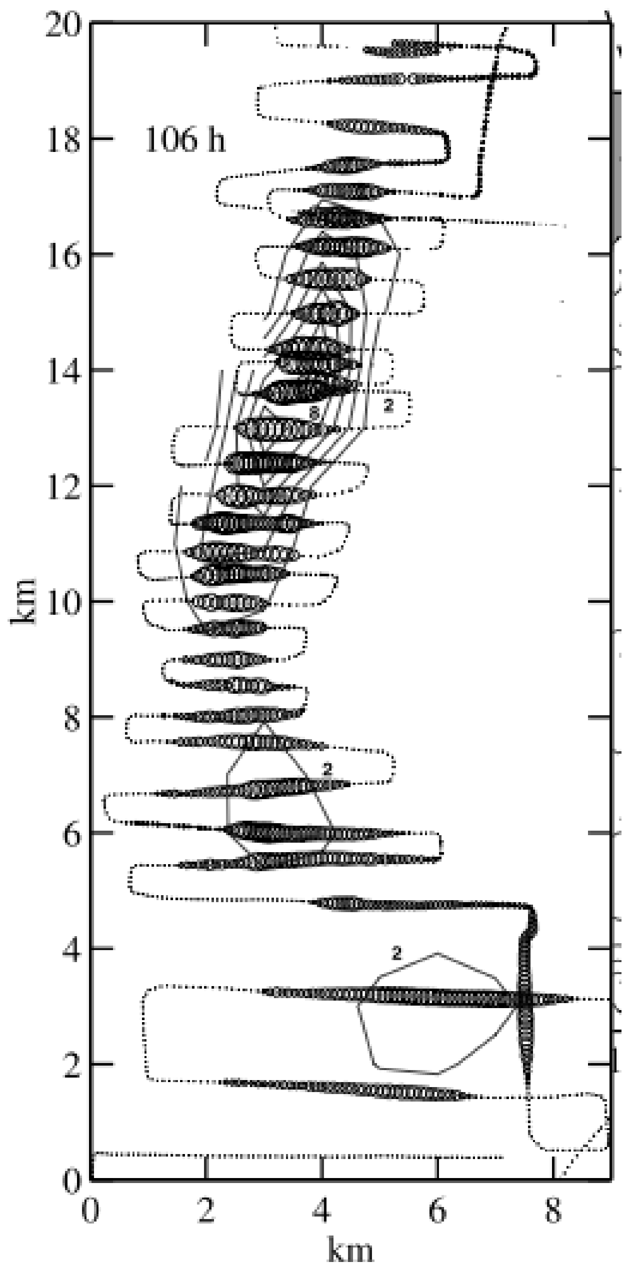

Figure 1 - an example of a radiator pattern mapping of a subsurface plume, from Ledwell et al. (2004).

We suggest that 3 vessels in addition to the validation vessel be put on alert to respond. They should be mobilized as the mapping exercise clarifies the existence, extent and complexity of the subsurface spill. At present the most appropriate vessels have not been identified. The need for low-frequency acoustic systems constrains eligible vessels.

An operations center to direct sampling and derive analyzed products will need to be established. Trained analysts on each sampling vessel will transmit an initial analysis of the acoustics and XBT information (or fluorometry if necessary) to the operations center. Doing so alleviates the need for high bandwidth communications from all vessels. A small team of analysts onshore will ingest and synthesize in the incoming information to derive regularly updated depictions of the plume structure. Satellite data will continue to be used to map the location of the surface oil plume and areas of suspected oil. Imagery derived from U.S. (NOAA 15, 16, 17, 18, 19 and NASA Terra and Aqua), as well as European (Metop_A and ENVISAT) satellites. The data will be remapped and re-navigated to a standard projection and recalibrated for the affected local regions of interest. Maps and ocean current movies will be derived daily and communicated with the researchers of the team, the research vessels, and other people who are interested in the data. The analysts will receive feedback from in-situ observations (ships and aircraft) and adjust their analyses accordingly. The maps will used to initialize various models used to forecast the motion of the oil – water mixture.

The 3D mapped distribution of the oil spill will be used to initialize model estimates of particle trajectories. Without an estimate of where the oil spill is at present an estimate of the total mass or its position over time is not possible. There are a number of full-depth circulation models of the Gulf that are in a position to simulate passive particle trajectories below the surface. The ability to assimilate hydrographic data that may be collected is not as broadly available. Support of an ensemble of modeling efforts would provide a range of solutions and permit some estimate of accuracy. There are also very high resolution surface plume models being considered that are capable of simulating detailed trajectories of oil along the coastline but the validity of the simulation will be constrained by the availability of reliable initialization data.

Once an initial mapping is completed a sustained monitoring effort should be established. The plume could be seeded with neutrally buoyant floats at key locations to provide continuous information on its movement. Profiling floats configured to drift along the isopyncals where oil has been found would be a cost-effective way to implement a monitoring program rapidly. There appear to be no ARGO floats in the Gulf of Mexico at present; deploying some in the field of the surface slick could be valuable, though fouling will likely compromise the conductivity measurements.

Biological sampling: A subsurface plume, if present, will affect a different set of organisms than will a plume of oil on the surface. Accurate determination of subsurface impacts will require detection and/or sampling of organisms at depth, as well as their environment. The following actions should be taken:

1. Initiate sampling of the pelagic and demersal ecosystem in the immediate area of the plume, and to the west. The Gordon Gunter (SEFSC) or similarly equipped vessel would be an ideal sampling platform. The cruise would collect organisms using trawls and MOCNESS plankton nets, and would collect samples water with a rosette sampler. Tissue and water samples would be analyzed for oil and dispersant related contaminants at the NMFS Seafood Safety Lab in Pascagoula, MS.

2. Collect historical information on distribution of organisms in the area of the plume from existing sources. Information on fish distribution from catch and fisheries-independent surveys is available at the SEFSC Pascagoula Lab and can be analyzed to determine the historical presence of fish and other organisms in the area of, and at the depth of, any detected plume. In addition, NOAA has information on deep sea corals and other habitats that can be analyzed for potential impacts. This will allow any sampling to be targeted to areas or likely impact.

Fate and transport modeling can help guide the longer-term mapping and measurement of the oil. Models can provide some insight into the expected signal levels (based on concentration in the water column), and the expected location of the oil. Models show that in the near field all the oil and gas in the plume rise at the same speed; in the far field the individual oil droplets move independently. These model outputs can help focus limited resources for mapping the plume boundaries over time.

There are two phases of modeling: the near field and far field. The near field is dominated by the plume dynamics near the source where the dispersed oil separates from the non-dispersed oil: its vertical distribution is critical in initializing the far field model. The far field model is dominated by the currents, diffusion parameters, and sink terms that define the concentration field kilometers to hundreds of kilometers from the source. Measurements of the near field can be used to validate the near field models. Vertical diffusion is expected to be minimal and horizontal diffusion small in the far field. This means that the concentration might stay in a measureable range tens of kilometers from the source, but the plume might be difficult to find.

Oil is removed from the water column by physical and biological processes. Marine snow and the vertical transport of sediments can sweep dispersed oil out of plume over time as it moves through the water with the deep water currents. Measurement of oil on the ocean floor could help identity the fate of the oil and length of the subsurface plumes.

Current Status – Modeling is already being conducted by NOAA OR&R and several expert modeling teams in the region. However, they have been limited by lack of observational data – hence the need for a comprehensive sampling plan. This is the main objective for the overall sampling strategy so that resulting modeling products can be used to inform near-term operational decisions and form a basis for trajectory forecasting.

Data Management and Logistics

Approach – This is a critical part of the overall sampling strategy. The basic approach is to aggregate validated sampling data via direction from the area command. This effort will be directed by the NOAA SSC at the area command. All observations that are developed under this overall plan will be transmitted to a NOAA-managed ftp server at the area command and then transmitted to the assigned modeling groups. This will establish an "authoritative source" for data, so that modeling efforts will maintain consistency and reliability. Sub-surface data can also be integrated with surface observations, shoreline data, and atmospheric conditions.

Modeling output can also be transferred to/from this ftp service, but will most effectively be managed by the modeling groups directly due to file size and format specifications. Coordination with the unified command priorities and field operations is critical. With numerous vessels, platforms, and activities in the region the operational unit leaders need to be made aware of any new sampling efforts or equipment being deployed. Informational updates will be provided on a daily basis to ensure the security and integrity of the sub-surface missions.

Current Status – NOAA OR&R has already established the ftp service and is currently managing all observational data. This process is being (and will be) communicated to all groups conducting sampling. A NOAA point of contact has been established for this process. A mission logistics coordinator will be needed to assist with coordination during the deployment phase. This POC will work closely with the sub-surface sampling coordinator (already on site).

References

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